

SELECTING HIGH-PRECISION PHOTOMETRY ON UNIFORM ZERO POINTS FOR FIVE BENCHMARK GALACTIC CLUSTERS

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ABSTRACT

This paper reviews results from two projects designed to yield photometry on uniform zero points for five clusters—Coma, the Hyades, M67, NGC 752, and Praesepe. Contributing papers for a project on Cousins *VRI* photometry and a project on Strömgren- β photometry are listed. Results of zero point tests of the photometry are reviewed, and their character is found to be satisfactory at the level of a few mmag. Responses to extant criticisms of the photometry are offered, and a section on $B - V$ photometry for the five clusters is included. Because the results of the projects suggest that certain changes should be made in current perspectives on photometry, those changes are reviewed. Finally, suggestions are made about future uses of data from the projects.

Subject headings: Hertzsprung-Russell diagram—open clusters and associations: individual (Coma, Hyades, M67, NGC 752, Praesepe)—stars: fundamental parameters (colors)

1. INTRODUCTION

In 1985 and 1992, we started “zero point” projects designed to yield photometry on uniform zero points for a number of galactic clusters. For five of them—Coma, the Hyades, M67, NGC 752, and Praesepe—complete results have now been published. Judging from ADS searches, however, at least some of those results are not as well known as they might be. In addition, readers of the papers from the projects would probably find it hard to put them in perspective.

Unavoidably, the papers are very detailed. As a result, potential users of the photometry from the projects would not find it easy to read straight through them. Even with the help

of their abstracts, it might be difficult for users to decide just how convincing each paper is. Currently, moreover, only fairly detailed comparisons among the papers could reveal which of them contain up-to-date data, which contain only superseded data, and which include discussions that are still topical. At present, it appears that at least one important project paper has been overlooked altogether. Finally, there is currently no published assessment of the coherence (or lack of coherence) of published photometry that has been surveyed during the course of the projects.

This paper addresses all of these problems. All papers produced by the two projects are listed, and potential users of the data are directed to papers that contain current results. Outcomes of zero point tests are summarized, and sources of more detailed information are cited. Because the conceptual foundation of the projects is controversial, existing criticisms of the photometry and our responses are discussed at some length. Given the results of the projects, some changes in outlook by photometric astronomers seem to be called for, and these are discussed. Finally, suggestions are made about possible use of project data.

Readers are invited to begin by reading §2 and a literature source cited there. Subsequent sections are concerned with Cousins *VRI* colors (§3), associated *V* magnitudes (§4), *B – V* colors (§5), Strömgren- β colors (§6), and a set of perspectives (§7). Readers who consult §3 are invited to look at §§3.1, 3.2, 3.8, 3.9, and the subsections concerning clusters of interest to them.

2. THE TWO PROJECTS: BASICS

2.1. Quantities measured, instrumental systems, and published papers

For one of the projects, the focus is on Strömgren- β measurements. The other project is concerned primarily with values of Cousins *VRI*. Papers from the latter project can be divided into a “Landolt” group and an “SAAO” group. Measurements in the Landolt group have been reduced to the Landolt (1983) system of standard stars. For this group, the principal source of current data is a paper co-authored with Elizabeth J. Jeffery (Taylor et al. 2008, hereafter TJJ).

Measurements in the “SAAO” group have been obtained at the South African Astronomical Observatory. Here, our collaborators have been C. David Laney and Francois van Wyk. To reduce measurements in this group, standard stars on the native Cousins system that have been calibrated at SAAO have been used. In addition to Cousins photometry, the papers in this group report values of *B – V*.

The character of the SAAO instrumental system plays a key role in our work (see §3). That system has a history of yielding stable transformations to the Cousins system (see, for example, §2 of Joner et al. 2006). Moreover, the SAAO system has been used extensively to establish Cousins *VRI* standards in the southern hemisphere (see, for example, Menzies et al. 1989; Kilkenny et al. 1998; Koen et al. 2002). For these reasons (see also §3.2), the SAAO system is regarded here as the most authoritative system of its kind.

All but one of the papers produced by the projects are listed in Table 1. A paper by Taylor & Joner (1996) that compares the Cousins and Landolt (1983) *VRI* systems is not listed in the table because it contains no cluster photometry. However, that paper should be regarded as part of the *VRI* project (see §3.1). We also note that the first SAAO paper listed in Table 1 has been cited several times (see, for example, Twarog et al. 2009 and Clem et al. 2011). However, TJJ has not been cited often, and it appears that its existence is not widely known. Potential users of project *VRI* data are therefore invited to adopt TJJ data for the Hyades, M67, Coma, and/or NGC 752. If Hyades data are used, the data specified in Table 2 may be added. Before that is done, however, users should make a point of reading the Table 2 footnotes.

A note is needed about project papers containing Hyades *VRI* data. Users who do not require Hyades values of $V - R$ can limit their attention to Table 2 and CDS data files from TJJ.¹ Those who wish to include Hyades values of $V - R$ should consult Taylor & Joner (1985), Joner et al. (2006), and Joner et al. (2008) and the footnotes given in Table 1 to the entries for those papers.

2.2. Aims, procedures, and zero point uniformity

One aim of the projects has been to determine exact relationships between their published data and the Cousins, Johnson, and Strömgren- β systems. A second aim (as noted in §1) has been to establish zero points that are known to be uniform from cluster to cluster. To support the latter aim, a number of nights have been used to compare two or three clusters directly. These “Sturch comparisons” imitate a procedure applied by Sturch (1972, 1973). In addition, zero point accuracy has been assessed from statistical comparisons of independent data sets (or “SCIDS” for short). The mean residuals obtained from SCIDS satisfy the so-called “FM” (“few millimag”) standard—that is, they are typically a few mmag in size. As explained in §§3–6, the mean residuals show that for each magnitude or color of

¹Except when required for the sake of clarity, subscript “C” for Cousins indices is omitted in this paper to simplify notation. However, subscript “L” (for Landolt) is used whenever it is required.

interest, zero points for the project data are coherent from cluster to cluster at the FM level.

2.3. Proof of concept

Both the SCIDS protocol and the FM standard have proved to be controversial. In part, this problem is due to two durable axioms. According to one of them (noted in §7.3 of Taylor & Joner 2006), the FM standard is rendered meaningless by a lower limit of about 10–20 mmag on the precision and accuracy of photometry. According to the other axiom (noted in §4.4 of TJJ), there is an inescapable danger that photometric transformations will compromise data accuracy. The second axiom is relevant here because SCIDS can be applied only to input data on a common photometric system. For that reason, transformations must be applied to some of those data before they are analyzed.

To put such issues in perspective, we note first that the zero point projects are based on a strictly Baconian outlook (see Bacon 1620, Second Book, aphorism 10). To paraphrase a relevant aphorism from that source: “We must not imagine or invent, but discover the properties of [the data themselves].” That is done solely by applying statistical analysis to them. In contrast, no authority is conceded to axioms like those cited just above.

To see where the Baconian protocol leads, readers are invited to consult the first two parts of §11 of TJJ. That discussion yields some pertinent conclusions. For one thing, no 10–20 mmag limit that would rule out the use of the FM standard exists. Moreover, transformations need not compromise data accuracy, even at the FM level. In their Table 14, TJJ display photometric data whose zero points cohere at that level. Additional examples of this sort are cited in §§3.3, 3.5, and 3.7. (For further evidence supporting the relevance of the FM standard, readers are invited to consult §7.3 of Taylor & Joner 2006.)

2.4. Zero point coherence: describing results

In the papers produced by the projects, offsets derived by applying SCIDS are quoted repeatedly. Quite often, results of tests for scale factor differences are reported as well. With one exception, however (see Table 5 of Taylor & Joner 2005), no such differences are detected. In response, only results from zero point tests are summarized here for the sake of brevity.

Let

$$M \equiv m \pm \sigma_m \tag{1}$$

refer to a formal correction to a new data set that is obtained by comparing it to an extrinsic data set. In the contributing papers, values of M tend to be reported in groups. To summarize results for a given group, one procedure adopted here is to state a value of

$$t \equiv |m/\sigma_m|. \tag{2}$$

This practice is based on the following lemma: if there are $N = 4$ or more values of M in a given group, and if $t < 2.5$ for all group members, it is fair to conclude that none of them differ from zero with a confidence level $C \geq 0.95$. This lemma does not depend on the value of N as long as $N \geq 4$, and it is independent of the number of degrees of freedom for each contributing datum.²

For some groups of interest, only maximum values of t are reported below. In these cases, readers should regard Table 14 of TJJ as an example while remembering that $t < 2$ in that case. Comments are added when a maximum value of t exceeds 2.5 or if at least one nonzero value of M is detected. If $N < 4$ or if values of M are scattered, informative values of M are quoted instead of a limit on t . For readers who desire further information, references to the project papers are given below. In particular, those references should be consulted for results of scale factor tests or to inspect all values of M in particular groups.

3. COUSINS *VRI* COLORS

3.1. Comparing the SAAO and 1983 Landolt systems

Because the *VRI* projects are based on two different systems of standard stars, there is an obvious need to understand the relationship between those systems. This problem has been investigated by a number of authors. However, the meaning of their results has been obscured by use of two different conventions for reporting them. Authors in the southern hemisphere prefer to work with values of $V - R$ and $V - I$. They find that for both indices, there are scale factor differences between the Landolt and southern hemisphere standard star

²The lemma is derived from an algorithm called false-discovery rate (or “FDR”; see Miller et al. 2001, especially §3 and Appendix B of that paper). Unlike a simple $t = 2$ detection threshold, FDR can be applied to the results of either single or multiple statistical tests. In their §2, Miller et al. 2001 discuss extensively the drawbacks of adopting the $t = 2$ threshold when multiple tests are performed.

data (see, for example, Fig. 2 of Menzies et al. 1991). On the other hand, authors in the northern hemisphere frequently adopt $R - I$ in place of $V - I$. For $R - I$, neither a scale factor difference nor a zero point difference between the two systems can be found (see Table 3 of Taylor & Joner 1996).

The choice made here is to work with $R - I$ and $V - R$. For the latter, a standard scale factor correction is adopted:

$$(V - R)_C = 0.989(V - R)_L, \quad (3)$$

with obvious notation (see §4.4 of Menzies et al. 1991 and eq. [5] of Taylor & Joner 1996). If possible, mean residuals in $V - R$ and $R - I$ are reported. When only values of $V - I$ are to be tested, equation (3) is applied (if necessary) and comparison data are then calculated by adding together values of $V - R$ and $R - I$.

3.2. Instrumental systems

The first values of Cousins $V - R$ and $R - I$ produced by this project were published by Taylor & Joner (1985). Those authors combined results from a variety of instrumental systems, with some requiring special transformation relations (see their §II). Though this procedure was successful (see especially §§3.4 and 3.5), it was also a stopgap device. Subsequently, a limited number of instrumental systems have been used instead. The scale factors of those systems do not differ from those of the adopted systems of standard stars by more than 10 percent. For the SAAO system, there are no differences as large as 5 percent. (For detailed information about the scale factors, see Table 1 of Joner et al. 2006.)

3.3. Hyades $R - I$

For the Hyades (and the other program clusters as well), values of $R - I$ have been used to calculate temperatures. Moreover, the accuracy of some of the Hyades data has been challenged (see §3.8). For these reasons, results from each step used to test the data will be reported in some detail.

In Taylor & Joner (1985), eight data sets are combined. For six of them, results of tests for zero point coherence are reported. Here, it is found that $t < 1.2$ (see Tables I and IV of Taylor & Joner 1985).

Taylor & Joner (2005) perform data tests in two steps. They find that measurements made by Mendoza (1967) differ from those of Taylor & Joner (1985), with $|M| = +11.8 \pm 2.9$ mmag. That difference affects a $V - I$ catalog published by Pinsonneault et al. (2004) because its entries are based on transformations of published photometry, with the Mendoza data included. If those data and the Pinsonneault et al. catalog results are set aside, tests using measurements from four extrinsic sources yield zero point coherence with $t < 1.8$.³ (For further information about those tests, see Table 1 of Taylor & Joner (2005).)

In their second step, Taylor & Joner (2005) compile an $R - I$ catalog using data from the 1985 paper and other sources (listed in Table 4 of Taylor & Joner 2005). Here also, an offset is found for the Mendoza data, as one might expect. However, data sets from five other extrinsic sources yield zero point coherence with $t < 2.0$. Except for the Mendoza data, there is no overlap between the extrinsic data sources used in this step and those used in the tests applied in the first step. (Sources of catalog data and pertinent values of M are listed in Tables 4 and 5 of Taylor & Joner 2005, respectively. Because a revised normalization is used for the Mendoza data, the result is a larger derived offset for those data than before: $|M| = +36.0 \pm 5.7$ mmag.)

Formal corrections to the 1985 and 2005 data are reported in Table 3 of Joner et al. (2006). Those corrections have been derived using SAAO data. For the epoch 1985 measurements, the SAAO data yield $M = -0.9 \pm 1.0$ mmag. For the epoch 2005 catalog data, $M = +0.1 \pm 1.0$ mmag. Given the latter result, the catalog data and the SAAO data can be combined readily. The resulting means are described in §10.1 of TJJ.

3.4. Hyades $V - R$

In this case, as for $R - I$, there is a published accuracy challenge (see §3.8). In response, two steps are taken. Taylor & Joner (1985) list seven contributing data sets, and they report the results of zero point consistency tests for all seven of them (see their Tables I and IV, respectively). Here, it is found that $t < 2.3$.

The results of $V - R$ tests performed by Taylor & Joner (2005) are not reviewed here because they are ambiguous (see §4.2 of Taylor & Joner 2005). In Joner et al. (2006), both SAAO data and measurements from the 2005 paper are brought to bear on the zero point

³We note that Clem et al. (2011) have adopted corrected entries from the Pinsonneault et al. catalog. Because data in that catalog have low precision, this is not the best available procedure. For a detailed critique of the Pinsonneault et al. catalog, see §§1, 2, and 4.3 of Taylor & Joner 2005. For Hyades data with acceptable precision, see the Hyades catalogs of TJJ.

problem. For data from Taylor & Joner (1985), the derived formal correction M is -3.5 ± 1.3 mmag. Though $t = 2.7$ for this residual, an analysis using false discovery rate reveals that it does not differ from zero with $C \geq 0.95$.

3.5. M67

TJJ present M67 data that are largely derived from new measurements. For a published source that contributes to the catalog, there is an accuracy challenge (see §3.8). Here, zero point comparisons are made between the catalog data and 13 other data sets, with $N = 6$, 4, and 3 for $R - I$, $V - R$, and $V - I$, respectively. If $V - I$ measurements by Sandquist (2004) and Montgomery et al. (1993) are set aside, it is found that $t < 2.5$ for the other 11 tests, with those using SAAO data being included. Judging from this consensus, the zero points of the TJJ data appear to be reasonably secure.

The Sandquist $V - I$ data yield a formal correction M to the TJJ data of -4 ± 1 mmag.⁴ This offset does not allow one to be sure that the zero point of the Sandquist data differ from those of the E region standards (see §6 of TJJ). However, the existence of the offset should not be overlooked.

For the Montgomery et al. values of $V - I$, evidence is found for a scale factor offset. In addition, the Montgomery et al. results are more positive than those of TJJ by 27 ± 1.3 mmag. Allowance for that offset appears to resolve a puzzling differential zero point problem discussed by VandenBerg & Clem (2003) and VandenBerg & Stetson (2004) (see §7 of TJJ). All told, there is a good case for not using the Montgomery et al. data in the future. (For more about the Montgomery et al. data, see §§4.3 and 5 of this paper. For details about the M67 data testing, see §§5.3 and 6 of TJJ and §5 of Joner et al. 2008.)

3.6. Coma

This cluster is too far north to be observed at SAAO. Partly for that reason, only one $V - R$ result from SCIDS is available. Using data from Taylor & Joner (2005), the value of M for the Taylor & Joner (1985) data is found to be $+2 \pm 1.5$ mmag.

For $R - I$, the Coma data of Taylor & Joner (1985) are based on a Sturch comparison of

⁴Here and for the Montgomery et al. data, quoted values of M differ from those in Table 5 of TJJ because the latter do not include an adjustment of 2 mmag. That adjustment is described in §5.3 of TJJ.

Coma, M67, and the Hyades (see Taylor 1978). Judging from an analysis of the resulting M67 data, the maximum correction that could be required for the Coma data of Taylor & Joner (1985) is about 2 mmag (see §5.3 of TJJ). In fact, two tests of the Coma data yield $M = -1 \pm 1.5$ mmag and $M = +2 \pm 1.4$ mmag, respectively. (For further information, see §8 of TJJ.)

3.7. Praesepe and NGC 752

For these clusters, there are not as many data sets as there are for the Hyades or M67, so not as many tests can be performed. In addition, only one of the clusters (namely, Praesepe) can be observed from SAAO. However, since Sturch comparisons of the clusters were performed frequently, SAAO data can be used to test the measurements for both of them. For $V - R$, two comparisons can be made, yielding $M = +3 \pm 2.3$ mmag and $M = -2.9 \pm 1.3$ mmag for the two clusters (see Table 7 of TJJ and Table 2 of Joner et al. 2011).

For values of $R - I$ for dwarfs, there is one discrepant value of M ($+6 \pm 1.4$ mmag). However, when SAAO data are included, t is found to be < 1.7 for four other such values. For $R - I$ measurements for giants in NGC 752, derived values of M are $+9 \pm 2.7$ mmag and -5 ± 2.9 mmag. The latter result is thought to be the more trustworthy of the two because it relates a formal zero point correction for NGC 752 to the well-supported formal correction for M67 (see §3.4). The $R - I$ results for NGC 752 are therefore accepted, though with an acknowledgment that they should eventually be tested further (see Table 2 of Joner et al. 2011 and §8 and Table 7 of TJJ).⁵

3.8. Accuracy challenges

To our knowledge, there are three extant challenges to the accuracy of our VRI colors. One of them is put forward in §2.2 of Vandenberg & Stetson (2004). The salient objectionable features of that challenge are *a*) use of data that have been described in print, but not published, *b*) use of data whose accuracy is irrelevant to our measurements, and *c*) substitution of inspection of graphs for statistical analysis. Responses to that challenge appear in

⁵Because of an editing oversight, there are references in §8 of TJJ to two “boldface” entries in Table 7 that are not actually given in boldface. In the order in which they are encountered in the discussion of TJJ, the entries in question are the third from the last and second from the last entries in the table.

§§4.1 and 12 of TJJ.

A second challenge concerns the Taylor & Joner (1985) transformations from instrumental to standard systems. As Joner et al. (2006) note in their §1, the accuracy of those transformations has been criticized. There is a key underlying assumption: if unsupported, qualitative objections are made to data provenance, the data themselves have to be inaccurate. Here, the axial issue is what the data themselves say. Alleged problems with the Taylor & Joner transformations cannot explain the coherence of their output—to say nothing of the support offered by subsequent measurements (see §§3.3 and 3.4).

A third challenge, offered by An et al. (2007), has not previously been assessed in the literature. Those authors assume axiomatically that only data obtained with a single instrumental system can be trustworthy. On that basis, An et al. (see their Appendix) adopt SAAO Hyades photometry from Joner et al. (2006) while rejecting the multi-source catalog of Taylor & Joner (2005). Here also, the axial issue is what the data themselves say. An et al. do not acknowledge that the data they accept have been used in successful SCIDS tests of the data they reject (again see §§3.3 and 3.4). Joner et al. highlight the results of those tests (see their §4.2) and list them in their Table 3. However, the only table in that paper considered by An et al. is Table 2, in which the Joner et al. photometric data are listed. Speaking as two of the co-authors of Joner et al. (2006), we find such selective citation of that paper to be open to serious question.

In assessing these criticisms, we have given priority to the published data themselves. In contrast, those who employ provenance reasoning or axioms have conferred ultimate priority on them. Judged in the context of the Baconian standard (recall §2.3), the resulting criticisms are not convincing. Nevertheless, it must be acknowledged that within the photometric discipline, the Baconian standard itself is apparently controversial.

Another concern has been our applications of statistical analysis to photometric data. In our correspondence with other photometrists, this issue has provoked the most forceful criticisms of the zero point projects that we have encountered. The instance put forward by VandenBerg & Stetson (2004) is actually a mild example of rejection of statistical analyses. As a rule, such rejections have taken place if the results of the analyses contradict axioms that are deemed to have priority. These rejections help to underscore the controversial character of the Baconian standard. (The outlook that would follow from general adoption of that standard is discussed in §7.)

3.9. Adopted sources of reddening values

In some CDS files produced by TJJ and Joner et al. (2011), data corrected for reddening (if necessary) are given. For that reason, reddening values must be known for all the program clusters. The reddening values adopted for the Hyades, Coma, and Praesepe have been derived by Taylor (2006). The adopted values for M67 and NGC 752 are given by Taylor (2007a) and Taylor (2007b), respectively.

For Praesepe and NGC 752, problems were encountered in deriving final reddening values. To assess the first of those problems, users of Praesepe data are advised to consult §9.1 of Taylor (2006). A quick way to assess the problem for NGC 752 is to look at the first two entries in Table 2 of Taylor (2007b). A full discussion of that problem is given in §5 of that paper.

The M67 reddening value adopted here is not accepted universally or without doubt (see, for example, Yadav et al. 2008). For that reason, readers are invited to gauge its rationale by consulting Tables 1 through 3 of Taylor (2007a). As those tables show, almost all M67 reddening work done before 2007 did no more than produce 70 values of $E(B - V)$ that range over 0.14 mag. Some authors still adopt one or more of those results without explanation (see Yadav et al. 2008; Friel et al. 2010). That practice is misleading because it effectively conceals the range of the 70 reddening values in the parent population. There is no reason to suppose that unexplained selections from those data bear any genuine relation to the actual M67 reddening value. By consulting Table 6 of Taylor (2007a), readers can see what was accomplished by adopting a fresh approach to the reddening problem. It is suggested that after inspecting Tables 1 through 3, users of M67 photometry disregard their contents altogether and adopt $E(B - V) = 41 \pm 4$ mmag from Table 6.

4. V MAGNITUDES FROM $BVRI$ PHOTOMETRY

4.1. Zero point comparisons: a first inspection

To assess V magnitude consistency, it is useful to start with Tables 8 and 9 of TJJ. The values of M given there range over about 60 mmag. The largest value of M listed by TJJ is based on data from Johnson & Knuckles (1955). The zero points for the measurements of Johnson & Knuckles are not definitive (for an explanation, see §7 of Joner et al. 2008). However, if values of M derived for their data are set aside, the range of the remaining values of M drops only to about 40 mmag. Here, then, no examples of consensus like those found for VRI colors appear. The task at hand is to satisfy the FM standard despite this obstacle.

4.2. Results for epoch 2011

The next step is to consult Joner et al. (2011). One issue discussed by those authors is the relationship between V magnitudes on the Johnson system and V magnitudes on the SAAO and Landolt (1983) systems. No color correction of SAAO V magnitudes appears to be required, and best evidence suggests that this is also true for Landolt (1983) V magnitudes (see §4 and Table 3 of Joner et al. 2011). The derived formal zero point correction for the latter (called M_3 here) is $+4.4 \pm 2.4$ mmag. Since the corresponding value of t is < 2 , M_3 does not differ from zero with $C \geq 0.95$. The corresponding result for SAAO V magnitudes is derived in two ways, with the results being $+6.8 \pm 1.1$ and $+2.0 \pm 0.8$ mmag, respectively. Though the first of these values is preferred, it is not regarded as definitive (see §5 and Table 4 of Joner et al. 2011).

Joner et al. (2011) also consider Hyades, M67, and Praesepe V magnitudes measured in the northern hemisphere. It is found that in effect, those data are on a single zero point (see Joner et al. 2011, Table 4, entries 3–5). This deduction should carry some weight because it seems unlikely to be an artifact of coincidence. Encouragingly, the formal difference between the three-cluster zero point and that of the Johnson system is the null value of M_3 quoted above.

4.3. Interpreting collected results

The final step is to interpret values of M collected from TJJ and Joner et al. (2011). For Coma, tests of data in the ‘Landolt’ group yield $M = -6 \pm 4$ mmag and $M = +2 \pm 3$ mmag. The latter value actually applies for combined Hyades and Coma measurements, and it is encouragingly consistent with the value of M_3 quoted just above. (The two quoted values of M are from the fourth and fifth entries in Table 8 of TJJ.)

For Praesepe and NGC 752, results may be treated as a unit (as noted in §3.7). Here, TJJ could not come to a definite conclusion because their derived values of M are scattered. With M_3 added, however, the balance of evidence favors a null V correction for both clusters. (For the results available to TJJ, see the last six entries in their Table 8.)

For M67, TJJ list eight values of M in their Table 9, with the largest being $+24 \pm 1$ mmag. However, only the last entry in that table relates the TJJ V data directly to the Johnson system.⁶ The implied correction to the TJJ data is formally zero, but has a 2σ

⁶In the second from last sentence in their §9, TJJ refer to that entry as a boldface entry. In fact, it is not

uncertainty of 12 mmag. With M_3 added, the implied correction is still formally zero, but the 2σ uncertainty drops to 4.8 mmag.

It should be noted (see Table 1 of TJJ) that an error that correlates with position on the face of the cluster has been detected in V magnitudes from Montgomery et al. (1993). There are also problems with values of $V - I$ and $B - V$ from that source (see §§3.5 and 5, respectively). All told, there is good reason to refrain altogether from using the Montgomery et al. BVI data in the future.

5. $B - V$ COLORS AND VALUES OF $[\text{Fe}/\text{H}]$

Color-magnitude analyses may include values of $B - V$ as well as VRI photometry. For that reason, it is worthwhile to specify $B - V$ sources for the program clusters. As it happens, the “L83” papers (see Table 1) include no $B - V$ photometry. Fortunately, there are useful results in the “SAAO” and other papers.

Typically, there are only two or three $B - V$ data sources of interest for each of the program clusters. An exception is M67, for which there are seven sources with values of $|M|$ ranging up to about +25 mmag. A zero point for those data has been derived from SAAO measurements and results from a Sturch comparison (see Sturch 1973). Users who are interested in further information about the zero point procedure applied in this case are invited to consult §8 of Joner et al. (2008).

The $B - V$ data sources we recommend for use are listed in Table 3. Instead of the results of comparisons among those sources, the table lists formal zero point corrections for each of them. Users who are interested in the provenance of those corrections are encouraged to consult either the footnotes to Table 3 or sources cited in the body of the table. If necessary, reddening corrections from sources listed in §3.9 should be applied to the adopted values of $B - V$.

Two data sources of potential interest are not listed in Table 3. Mendoza (1967) data are excluded because more precise results are available from sources listed in Table 3. $B - V$ measurements given by Montgomery et al. (1993) are excluded because they appear to be on two decisively different zero points (see §8 and entries 6 and 7 in Table 5 of Joner et al. 2008). VRI results from Montgomery et al. are also not recommended for future use (see §§3.5 and 4.3).

in boldface because of a proofreading error. However, the TJJ reference does designate the correct entry in their Table 9.

Table 3 includes two entries for Hyades data sets. However, we recommend that for single Hyades stars, the following convenient equations be used instead (see §6 of Joner et al. 2008):

$$B - V = \sum_{i=0}^3 C_i r^i, \quad (4)$$

with $r \equiv (R - I)_C$;

$$[C_0, C_1] = [(0.244 \pm 0.001), (-1.13 \pm 0.41)]; \quad (5)$$

and

$$[C_2, C_3] = [(9.53 \pm 1.45), (-7.89 \pm 1.61)], \quad (6)$$

with $0.11 \text{ mag} \leq (R - I)_C \leq 0.50 \text{ mag}$.

Because $B - V$ measurements are sensitive to blanketing, they must be analyzed with the help of cluster metallicities. For four of the program clusters, values of $[\text{Fe}/\text{H}]$ that were current at time of publication are given in the reddening papers cited in §3.8. For Praesepe, an updated value of $[\text{Fe}/\text{H}]$ appears in Taylor (2008). It should be noted that these values of $[\text{Fe}/\text{H}]$ apply for temperatures on an angular diameter scale (see Taylor 2007a, Appendix B, entry 4). Though the corrections to published data that are required to put them on that scale are often small, it should not be forgotten that those corrections have been applied. For that reason, the resulting values of $[\text{Fe}/\text{H}]$ are not strictly comparable to counterparts in the literature.

6. THE STRÖMGREN- β PROJECT

When this project began, it was known that there are appreciable zero point differences between a number of published Strömgren- β data sets (see, for example, the Appendix of Nissen et al. 1987). To deal with such problems, the project aims to “. . . test the consistency of Strömgren- β photometry for lightly reddened galactic clusters” (see §1 of Joner & Taylor 1997). To make that possible, Sturch comparisons have been used to build up a system of standard-star data on a uniform zero point. That system is based on measurements of the Hyades and Coma, for which extant data (Crawford & Perry 1966; Crawford & Barnes 1969) turn out to share a common zero point. The Hyades-Coma paper (see Taylor & Joner

1992) and three others produced by the project are listed in Table 1. Joner & Taylor (2007) have presented comparable results for the Pleiades, and Joner et al. (1995) have added an auxiliary paper on the photometry of Grønbech & Olsen (1976, 1977).

Relative to the Hyades-Coma system, offsets have been detected for M67, Praesepe, and NGC 752. For the latter two clusters, all but one of the derived values of $|M|$ (with M being a mean residual; see eq. [1]) range from zero to $+19.0 \pm 3.4$ mmag. For M67, values of $|M|$ as large as $+61.0 \pm 5.8$ mmag have been found (see Tables 4 and 5 of Joner & Taylor 1997 and Table 6 of Joner & Taylor 2007.) To date, data from the project have been used in zero point tests and color-color diagnosis (see, for example, Anthony-Twarog & Twarog 2006 and Kinman 1998, respectively). Use of project results to establish cluster measurements as standard-star data is also possible (see, for example, Appendix B of Joner & Taylor 1995).

7. PERSPECTIVES

To grasp the overall results of the zero point projects, suppose first that the Baconian standard (recall §2.3) were to prevail throughout the photometric discipline. As one outcome, statistical analysis would be applied dependably to photometric data sets, and the results would take precedence over all contrary axioms about the alleged character of the data (see §3.8). A second outcome would be increased caution about gauging photometric quality. Too often, discourse among photometric astronomers takes place in an eye-smarting haze of skepticism about the quality of published photometry. Inventing poorly supported and often specious criticisms of such data is a widespread practice (see, for example, objections discussed in §3.8 and a class of criticisms diagnosed in §7 of Taylor & Joner 2005).

After the changeover to the Baconian standard, a lesson taught by photometric zero points would attract notice. It would be acknowledged that maximum values of $|M|$ can be about 86 mmag (see Table 3 of Stetson et al. 2004), 40–60 mmag (see §§4.1 and 6), 25 mmag (see section 5), and $\leq 0.9 \pm 1.0$ mmag (see §3.3). In response, there would be no generalizations about any alleged limit to zero point coherence (see notably Stetson et al. 2003 and §3 of Stetson et al. 2004). Instead, particular data sets would be gauged solely on their particular merits and demerits.

Yet another result would be a reluctance to “block the road of inquiry” (to quote Charles Sanders Peirce). It would be recognized that skepticism about published data is not conducive to putting them to good use. Ways of doing that would receive greater attention and would be more widely practiced. Using extant photometry to derive and apply standard corrections to data sets (see §§3.1 and 5) is one example of such practice. The

Mendoza (1967) data offer another example: if Hyades measurements are used to calculate an auxiliary transformation for those data, measurements of other clusters made by Mendoza can then be compared usefully to counterparts from other sources despite the relatively low precision of the Mendoza data. (For the auxiliary transformation, see eqs. [A5] in Table 9 of Taylor & Joner 2005. For a fully successful use of the Mendoza data, see Table 7 of TJJ.) Finally, zero point jitter in existing data for given clusters would not be accepted indefinitely. Instead, Sturch comparisons would be employed, as in an example to be given just below.

To potential users, we suggest three ways of using data from the zero point projects. There is sizeable zero point jitter in extant photometry for NGC 188 (see again Table 3 of Stetson et al. 2004). To derive reliable zero points for that photometry, Sturch comparisons of NGC 188 and M67 could be performed at equal air mass. The results could then be reduced by using M67 data from TJJ. In addition, a test could be performed to see whether $V - I$ measurements for the Hyades and M67 can be matched simultaneously to theoretical isochrones (see §3.5). Finally, statistical algorithms for color-magnitude analysis (see, for example, Jørgensen & Lindegren 2005) could be applied to project data. The aim would be to derive ages and distance moduli for the program clusters with the highest possible precision.

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Table 1. List of project *VRI* and Strömgren- β papers

Paper	Group ^a	Use data?	Clusters ^b	Paper	Group ^a	Use data?	Clusters ^b
Taylor (1978) ^c	L83	N	H,C,M67	TJJ	L/S	Y ^d	5
Taylor & Joner (1985)	L83	Y ^e	H,C,M67	Joner et al. (2008)	SAAO	Y ^f	H,M67
Joner & Taylor (1988) ^g	L83	N	H,M67	Joner et al. (2011)	SAAO	Y ^h	H,Pr
Taylor & Joner (1988)	L83	N	H,M67	Taylor & Joner (1992)	Str	Y ⁱ	H,C
Joner & Taylor (1990) ^g	L83	N	M67	Joner & Taylor (1995)	Str	Y ⁱ	Pr,752
Taylor & Joner (2005)	L83	N	H	Joner & Taylor (1997)	Str	Y ⁱ	M67
Joner et al. (2006)	SAAO	Y ^j	H	Joner & Taylor (2007)	Str	N ^k	Pr

^a“L83”: Cousins *VRI* reduced to the Landolt (1983) standard-star system. “SAAO”: $B - V$ and Cousins *VRI*, South African Astronomical Observatory. “L/S”: combined L83 and SAAO measurements. “Str”: Strömgren- β measurements.

^b“H,” “C,” “M67,” “Pr,” and “752” refer to the Hyades, Coma, M67, Praesepe, and NGC 752, respectively. “5” means that all five clusters are considered.

^cTo see how data from this paper have been used, look at the entry for run 3 in §II of Taylor & Joner (1985).

^dFor the Hyades, CDS files for this paper contain combined northern-hemisphere and SAAO data. For all program clusters except Praesepe, CDS files from TJJ should be consulted. For Praesepe data, see Joner et al. (2011).

^eDespite the headings in Table V of Taylor & Joner (1985), values of $(V - R)_L$ —not $(V - R)_C$ —are given there. Hyades values of $(V - R)_L$ data from Table V may be adopted if they are not flagged with an asterisk. They may then be converted to Cousins values of $V - R$ by applying eq. [3].

^fThe TJJ M67 measurements are adequately precise without being combined with data given by Joner et al. (2008). For Hyades data from that paper that are to be added to the TJJ CDS data files, see Table 2. Hyades values of $V - R$ are available from Joner et al. (2008).

^gBoth the data and the discussion in the listed paper have been superseded.

^hA CDS file is available containing combined Praesepe data from TJJ and Joner et al. (2011). The TJJ Hyades measurements are adequately precise without being combined with data given by Joner et al. (2011).

ⁱThe listed paper includes newly published Strömgren- β measurements. These may be combined with photometry (corrected, if necessary) from previously published sources cited in the listed paper.

^jUse only Hyades $V - R$ measurements from Joner et al. (2006). For other Hyades data, see TJJ and Table 2 of this paper.

^kJoner & Taylor (2007) do not give new data for the five clusters of interest here, but do give such data for the Pleiades.

Table 2. Additions to the TJJ Hyades data

vB ^a	HIP	$R - I^b$	$(V - K)_J^c$	θ^d	V^e
231	19207	0.583(3.0)	2.764(11)	1.147(2.1)	10.469(3.0)
253 ^f	—	—	—	—	—
262	20527	0.665(3.0)	3.067(11)	1.201(1.9) ^g	10.876(4.5)
291	21261	0.596(3.0)	2.812(11)	1.155(2.0)	10.691(5.2)
311	21723	0.516(4.2)	2.516(16)	1.098(3.1)	10.024(10.)
324	—	0.508(3.0)	2.486(11)	1.092(2.2)	9.827(4.5)
—	19808	0.637(3.0)	2.964(11)	1.183(1.9)	10.679(2.7)

NOTE.—These data are not in the TJJ CDS data file for the Hyades. Before deciding to add them to that file, users are urged to be sure that the character of the data is understood.

^aThis is the van Beuren (1952) number.

^bThis entry is from Table 1 of Joner et al. (2008). The entries in parentheses are standard errors in mmag with an adopted lower limit of 2.9 mmag.

^cThe entries in parentheses are standard errors in mmag. For the sake of consistency with existing results, all quoted values of $(V - K)_J$ have been transformed from the values of $R - I$ in the third column using a relation given in Table 4 of TJ06. Adopting the modification for red stars given in the Appendix of Joner et al. (2008) would change the resulting values of $(V - K)_J$ by less than 1σ .

^dAs usual, $\theta \equiv 5040/T_{eff}$. The entries in parentheses are standard deviations multiplied by 1000.

^eThese entries are from Table 1 of Joner et al. (2008), with a compromise correction of 4 mmag added (see Joner et al. (2011), Table 4, entries 11 and 13).

^fThere is a 3σ difference between the values of $R - I$ given for this star by TJJ and Joner et al. (2008). The TJJ entry for this possible variable star should therefore be deleted.

^gThis value of θ is from an extrapolation of the Di Benedetto (1998) temperature scale and so should be used with caution.

Table 3. Recommended $B - V$ sources for program clusters

Cluster	Paper ^a	Correction (mmag)	Apply?	Source paper ^b	Table ^c	Error (mmag)	Kind ^d
Hyades	JK55	-3.5 ± 1.3^e	Y	SAAO II	Table 4	10^f	R
Hyades	SAAO I	-9.4 ± 1.5^e	Y	SAAO II	Table 4	–	I
M67	SAAO II ^g	$+2.3 \pm 2.4$	N	SAAO II	Table 5	–	I
M67	S04	$+2.3 \pm 2.4$	N	SAAO II	Table 5	13	S
Praesepe	J52,DKK ^h	-2.9 ± 3.0	N	SAAO III	Table 2	10^f	R
Praesepe	SAAO III	-9.4 ± 1.5	Y	SAAO II	Table 4	–	I
Coma	JK55	-2.3 ± 2.7	N	New ⁱ	–	10^f	R
NGC 752	J53	-14.3 ± 3.1	Y	New ⁱ	–	10^f	R
NGC 752	E63	-9.4 ± 3.2	Y	New ⁱ	–	10	R

^aThese papers present the data to be adopted. “DKK” is Dickens et al. (1968); “E63” is Eggen (1963); “J52” is Johnson (1952); “J53” is Johnson (1953); “JK55” is Johnson & Knuckles (1955); “S04” is Sandquist (2004); “SAAO I” is Joner et al. (2006); “SAAO II” is Joner et al. (2008); and “SAAO III” is Joner et al. (2011).

^bThese are the source papers for the quoted corrections. “SAAO II” is Joner et al. (2006); “SAAO III” is Joner et al. (2011); “New” refers to this paper.

^cEach listed table appears in the source paper in the previous column.

^d“I”: standard errors are quoted in the data table. “R”: the quoted error is an rms error. “S”: the quoted error is a standard error.

^eFor a preferred source of $B - V$, see eqs. [3]–[5] in the text.

^fJohnson implies that the rms error for his data is 7 mmag.

^gSee Table 6 of the listed paper. Because rezeroed SAAO measurements from Table 2 of that paper contribute to its Table 6, no entry for the Table 2 data is given here.

^hData from the two listed papers are effectively on the same zero point; see Joner et al. (2011), Table 2, entry 6.

ⁱThis correction is derived by using extrinsic data from eq. [1] of Joner et al. (2006). For source data, see measurements and sources quoted by Taylor & Joner (1992) and Joner & Taylor (1995).